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(54) **METERING CIRCUIT INCLUDING A FLOATING COUNT WINDOW TO DETERMINE A COUNT**

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H03K 5/1532	(2006.01)
H03K 23/64	(2006.01)
G01R 23/10	(2006.01)

(52) **U.S. Cl.**
CPC ***H03K 21/10*** (2013.01); ***B67D 7/228*** (2013.01); ***H03K 5/1532*** (2013.01); *B65H 2220/01* (2013.01); *B65H 2513/11* (2013.01); *G01R 23/10* (2013.01); *H03K 23/64* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,045,728	A	8/1977	Fletcher et al.	
6,549,120	B1	4/2003	de Buda	
7,723,979	B2	5/2010	Ashburn	
2009/0189778	A1	7/2009	Juan et al.	
2010/0302061	A1	12/2010	Winter et al.	
2011/0182398	A1*	7/2011	Iwashita et al.	377/19
2013/0167652	A1*	7/2013	Pflum et al.	73/861
2013/0197831	A1*	8/2013	Yonezawa et al.	702/47
2013/0269447	A1*	10/2013	Takemura et al.	73/861.27
2015/0035509	A1*	2/2015	Koyama et al.	323/283
2015/0177280	A1*	6/2015	Berringer	G01R 15/00

* cited by examiner

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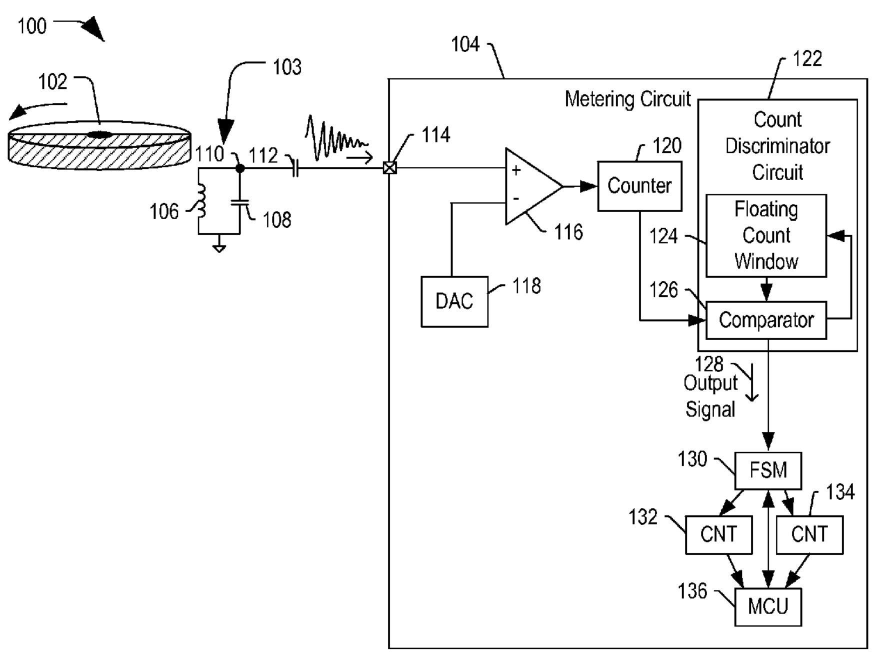
(57) **ABSTRACT**

A method includes receiving a count corresponding to a number of peaks of a resonant signal that exceed a reference signal and comparing the count to a floating count window defined by a first count threshold and a second count threshold, the first count threshold is larger than the second count threshold. The method further includes selectively shifting the floating count window in a direction of the count when the count falls outside of the floating count window.

20 Claims, 6 Drawing Sheets



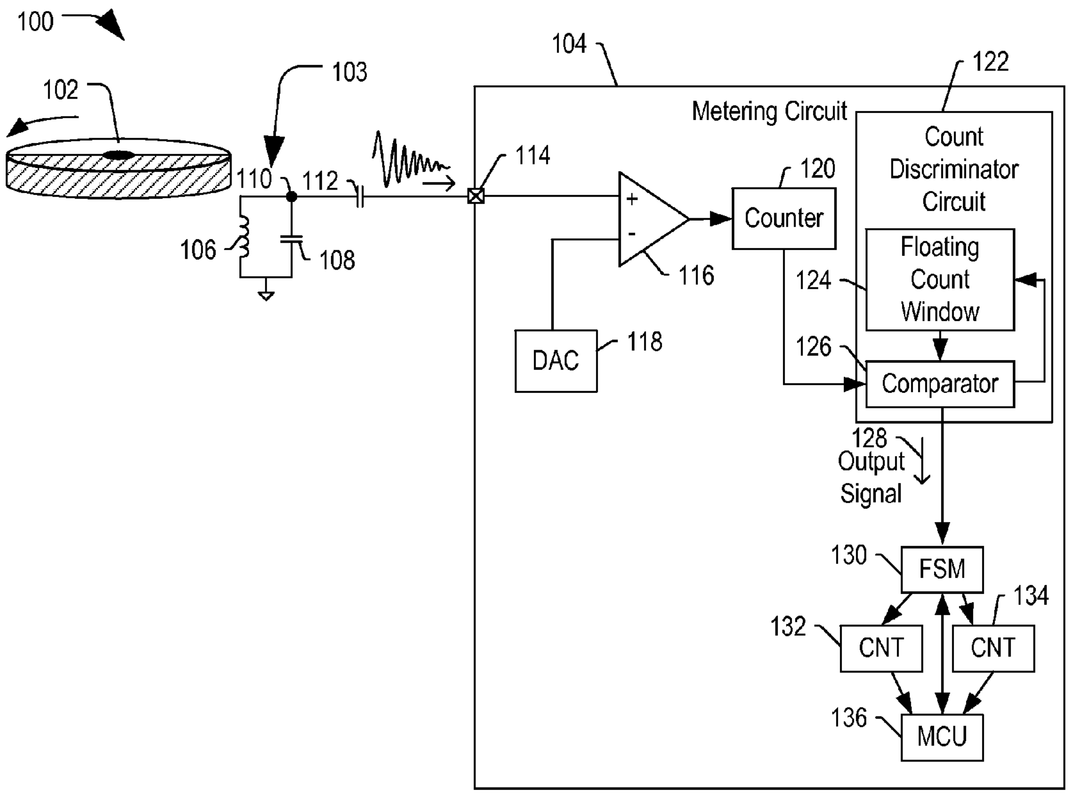

100
102
103
110
112
106
108
104
Metering Circuit
114
+
-
116
118
DAC
120
Counter
122
Count Discriminator Circuit
124
Floating Count Window
126
Comparator
128
Output Signal
130
FSM
132
CNT
134
CNT
136
MCU

FIG. 1

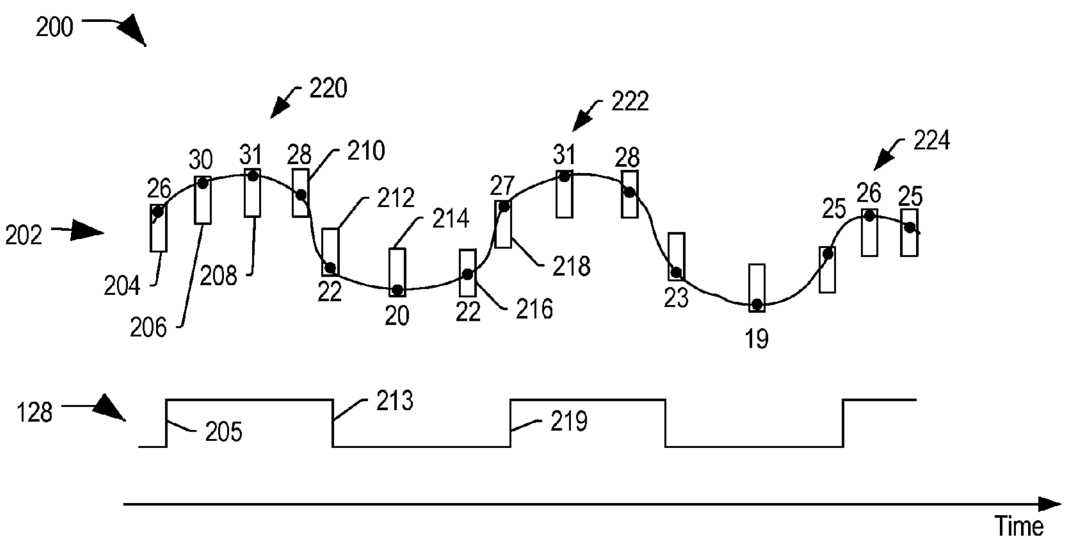

200
220
222
224
26
30
31
28
210
212
214
27
31
28
25
26
25
202
218
204
208
22
20
22
216
23
206
19
128
205
213
219
Time

FIG. 2

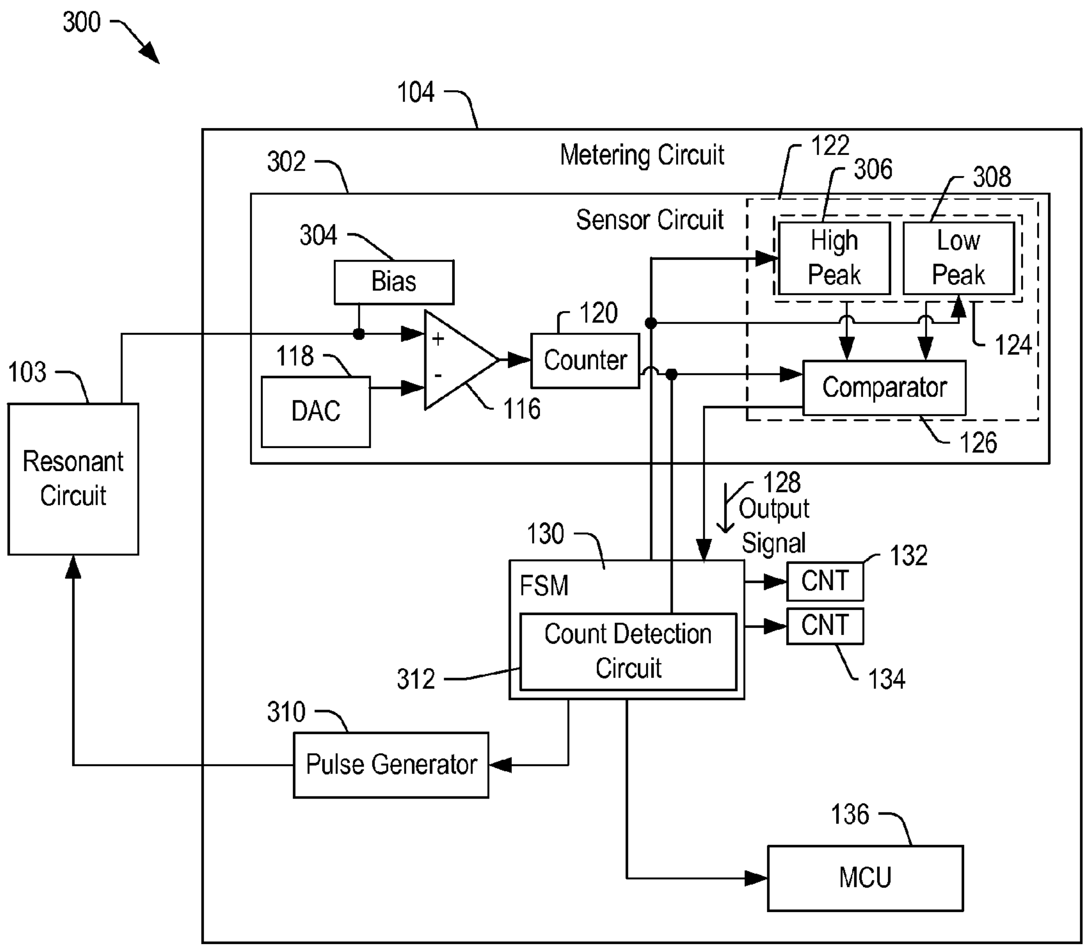

300
104
Metering Circuit
302
Sensor Circuit
122
306
308
304
Bias
High Peak
Low Peak
120
Counter
124
103
118
DAC
116
Comparator
Resonant Circuit
126
128
Output Signal
130
132
FSM
CNT
CNT
Count Detection Circuit
134
312
310
Pulse Generator
136
MCU

FIG. 3

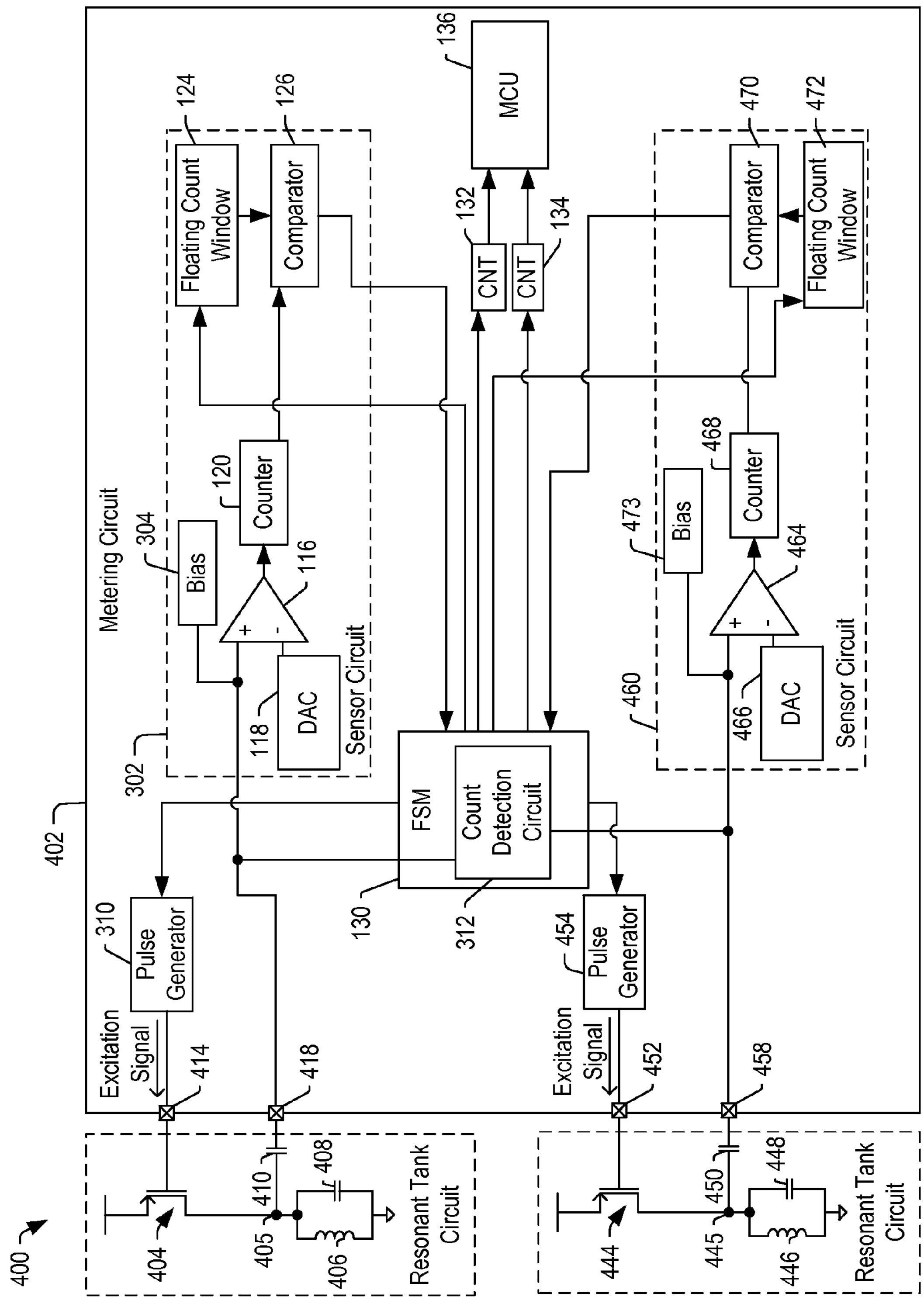

400
402
Metering Circuit
Floating Count Window
124
Comparator
126
MCU
136
CNT
132
CNT
134
Comparator
470
Floating Count Window
472
302
Sensor Circuit
Bias
304
Counter
120
116
118
DAC
FSM
Count Detection Circuit
130
312
460
Sensor Circuit
Bias
473
Counter
468
464
466
DAC
Pulse Generator
310
Pulse Generator
454
Excitation Signal
414
418
Excitation Signal
452
458
404
405
410
408
406
Resonant Tank Circuit
444
445
450
448
446
Resonant Tank Circuit

FIG. 4

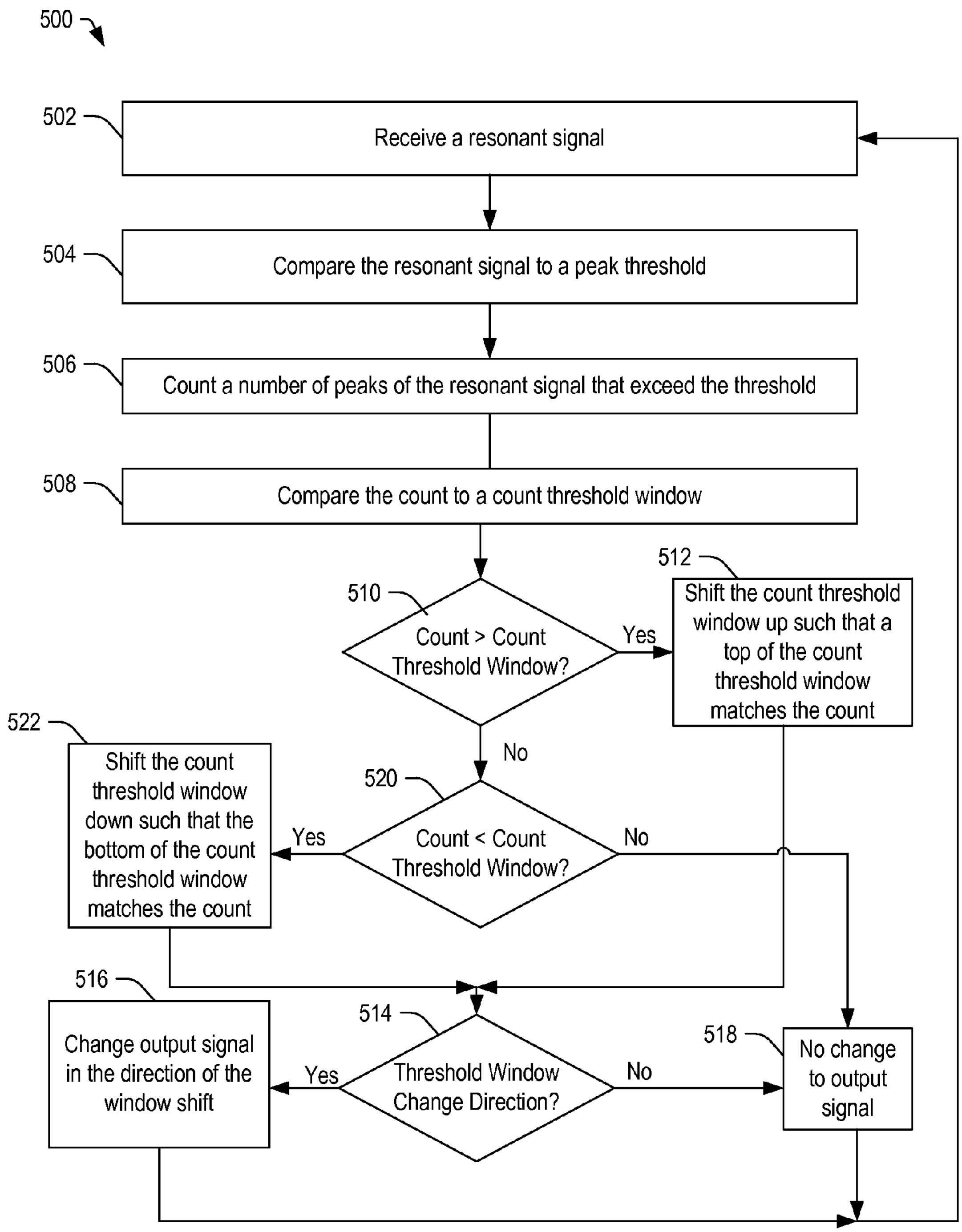

500
502
Receive a resonant signal
504
Compare the resonant signal to a peak threshold
506
Count a number of peaks of the resonant signal that exceed the threshold
508
Compare the count to a count threshold window
510
Count > Count Threshold Window?
Yes
512
Shift the count threshold window up such that a top of the count threshold window matches the count
No
520
Count < Count Threshold Window?
Yes
No
522
Shift the count threshold window down such that the bottom of the count threshold window matches the count
516
Change output signal in the direction of the window shift
514
Threshold Window Change Direction?
Yes
No
518
No change to output signal

FIG. 5

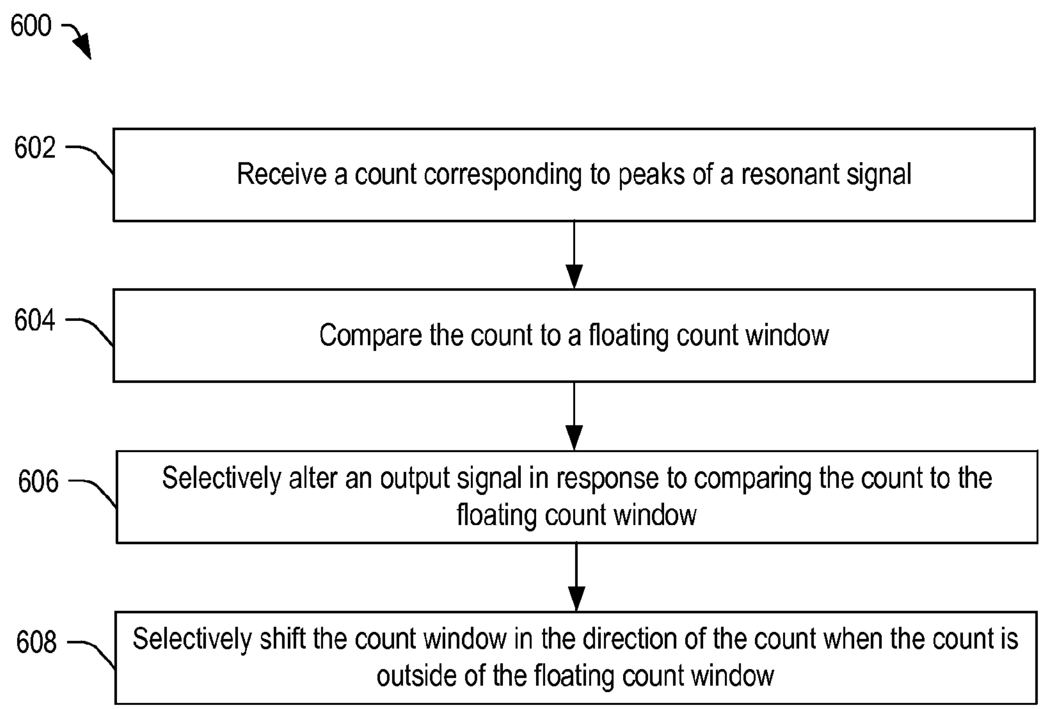

600
602
Receive a count corresponding to peaks of a resonant signal
604
Compare the count to a floating count window
606
Selectively alter an output signal in response to comparing the count to the floating count window
608
Selectively shift the count window in the direction of the count when the count is outside of the floating count window

FIG. 6

METERING CIRCUIT INCLUDING A FLOATING COUNT WINDOW TO DETERMINE A COUNT

FIELD

The present disclosure is generally related to metering circuits, such as circuits configured to count signal peaks from a ringing signal to determine usage of a utility, for example.

BACKGROUND

Water and gas meters use a variety of measuring and sensing techniques. One method of sensing position and rotation of a metering apparatus uses inductor-capacitor (LC) sensing, which employs an LC resonant circuit. An LC meter interface may stimulate the LC resonant circuit and measure the response (a ringing waveform).

SUMMARY

In an embodiment, a method includes receiving a count corresponding to a number of peaks of a resonant signal that exceed a reference signal and comparing the count to a floating count window defined by a first count threshold and a second count threshold, the first count threshold is larger than the second count threshold. The method further includes selectively shifting the floating count window in a direction of the count when the count falls outside of the floating count window.

In another embodiment, a metering circuit includes a first comparator including an input to receive a resonant signal, a second input to receive a reference signal, and an output. The metering circuit further includes a counter including an input coupled to the output and including an output to provide a count corresponding to a number of peaks of the resonant signal that exceed the reference signal. The metering circuit also includes a second comparator to compare the count to a floating count window defined by a first count threshold and a second count threshold and a controller coupled to an output of the comparator and configured to selectively shift the floating count window in a direction of the count.

In still another embodiment, an apparatus includes a first comparator having a first input to receive an input signal, a second input to receive a reference signal, and an output. The apparatus further includes a counter having an input coupled to the output of the first comparator, and includes an output to provide a count. The apparatus also includes a count discriminator circuit to compare the count from the counter to a floating count window and to shift the floating count window to match the count when the count falls outside of the floating count window.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a system including a metering circuit employing a floating count window to determine a count according to an embodiment.

FIG. **2** is a diagram of peak counts over time and of a corresponding output signal over time for the metering circuit of FIG. **1**, according to an embodiment.

FIG. **3** is a block diagram of a system including a metering circuit employing a floating count window to determine a count according to a second embodiment.

FIG. **4** is a block diagram of a system including a metering circuit employing a floating count window to determine a count according to a third embodiment.

FIG. **5** is a flow diagram of a method of determining a count using a floating count window according to an embodiment.

FIG. **6** is a flow diagram of a method of determining a count using a floating count window according to a second embodiment.

In the following discussion, the same reference numbers are used in the various embodiments to indicate the same or similar elements.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Metering circuits often use a threshold to compare against an input signal to decide whether a condition is met. However, changes in temperature and voltage may change the input signal and/or the threshold. Instead of performing calibrations to adjust the threshold for such changes, embodiments of a metering circuit are described below that use a floating count window to track changes in the detection of the input signal. In particular, embodiments of the metering circuit utilize a count window having a pre-defined size that is smaller than a difference between an upper count corresponding to a first state of a system and a lower count corresponding to a second state of the system. By sizing the count window to be smaller than such a difference, changes in the count will move the window up or down, which directional changes can be represented by a change in a state of the output signal, representing a change in state of the system. An embodiment of such a metering circuit is described below with respect to FIG. **1**.

FIG. **1** is a block diagram of a system **100** including a metering circuit **104** employing a floating count window to determine a count according to an embodiment. The system **100** includes a wheel **102** that rotates in response to flow of a consumable element, such as electricity, water, gas, or other measurable substance. The wheel **102** includes a metallized portion (represented by the hash marks) and a non-metallized portion.

The system **100** further includes a resonant tank **103**. The resonant tank **103** includes an inductor **106** in parallel with a capacitor **108**, which are coupled between a node **110** and a power supply, such as ground. The node **110** may be coupled to the metering circuit **104** through a capacitor **112**.

The metering circuit **104** includes an input **114** (such as a pad) that is coupled to the capacitor **112** and to a positive input of a comparator **116**. The comparator **116** includes a negative input coupled to a digital-to-analog converter (DAC) **118**, which operates as a programmable reference to supply a reference voltage to the comparator **116**. The comparator **116** also includes an output to provide pulses representing peaks in the input waveform to a counter **120**. The counter **120** provides a count signal, representing the number of peaks of the input waveform that exceed the threshold signal provided by the DAC **118**, to an input of a comparator **126** of a count discriminator circuit **122**. The comparator **126** includes a second input to receive threshold signals corresponding to a floating count window **124**, and includes an output to provide an output signal **128** to an input of a controller, such as a finite state machine (FSM) **130**. The FSM **130** may update count registers **132** and **134** and may be coupled to a microcontroller unit (MCU) **136**.

In an embodiment, the metering circuit **104** may be used to detect peaks in a resonant signal from the LC tank circuit **103**. The LC tank circuit **103** may be energized, and the energy resonates back and forth between the capacitor **108** and the inductor **106** while decaying due to inductor resistance and magnetic flux loss, producing a ringing waveform at the input **114** of the metering circuit **104**. The duration of the decaying sine wave (ringing waveform) can be determined by counting the number of peaks of the ringing waveform. When a metalized section of the wheel **102** is proximate to the inductor **106** of the LC tank circuit **103**, some of the magnetic flux will be absorbed by the metal, causing the sine wave to decay faster and reducing the number of peaks (counts), i.e., damping the input signal.

The comparator **116** receives the ringing waveform at its positive input and compares the waveform to a reference signal from the DAC **118**. The comparator **116** produces output signal pulses that represent the peaks that exceed the reference signal. The counter **120** counts the pulses and provides the count to the comparator **126**. The comparator **126** compares the count to the floating count window **124** and produces an output signal **128** based on the comparison. If the count falls within the floating count window **124**, the comparator **126** continues producing the same output signal that it was already producing. However, if the count falls outside of the floating count window **124**, the count discriminator circuit **122** pushes the floating count window **124** in the direction of the count. Additionally, the comparator **126** produces an output signal corresponding to the direction in which the floating count window **124** changes.

The floating count window **124** pushes one direction at a time. Each time a higher count is detected, the count discriminator circuit **122** changes the floating count window **124** to the higher count value, and the comparator **126** outputs a logic high signal. When the counts start decreasing, the count discriminator circuit **122** does not change the floating count window **124** until the count from counter **120** is small enough to push the bottom of the floating count window **124**, at which point the comparator **126** changes its output from a logic high level to a logic low level. The count discriminator circuit **122** changes the floating count window **124** in the downward direction corresponding to the count. The count discriminator circuit **122** continues to change the floating count window **124** in the downward direction until the counts begin to increase. Once again, the floating count window **124** and the value of the output signal **128** of the comparator **126** do not change until the count is high enough to exceed the top of the floating count window **124**. Once the count pushes the upper boundary of the floating count window **124**, the output signal **128** of the comparator **126** changes from a logic low level to a logic high level. Additionally, the count discriminator circuit **122** shifts the floating count window to match the count.

FIG. **2** is a diagram **200** of peak counts **202** over time and of a corresponding output signal **128** over time for the metering circuit **104** of FIG. **1**, according to an embodiment. The diagram **200** further includes floating count windows **204**, **206**, **208**, **210**, **212**, **214**, **216** and **218**, which represent upper and lower boundaries that define a count differential that is less than a difference between a typical undamped count and a typical damped count of peaks of the input signal.

As the wheel **102** turns, the number of counts of the input signal at input **114** vary, as reflected in signal **128**. In the illustrated example, the number of peaks of the input signal vary between approximately 19 (damped signal count) and 31 (undamped signal count). However, any count range can be used provided that the count is several counts less than a count difference between the highest count and the lowest count, making it possible for the count to push the floating count window up or down.

Referring now to the peak counts **202**, the count value is 26 at floating count window **204**, which pushes the floating count window **204** up causing the comparator **126** to change its output signal **128** from a logic low level to a logic high level at transition **205**. The count value increases to 30 at floating count window **206** and to 31 at floating count window **208**, which counts push the floating count windows **206** and **208** upward; however, since the direction of the push hasn't changed, the output signal **128** does not transition. At window **210**, the count value decreases to 28; however, the floating count window **210** is larger than three, so the decrease from a count of 31 to a count of 28 is insufficient to shift the floating count window **210** down, and thus the output signal **128** remains at a logic high level.

At floating count window **212**, the value of the peak counts **202** has fallen to 22, pushing the floating count window **212** down. In response to or in conjunction with the shifting of the floating count window, the output signal **128** of the comparator **126** transitions from the logic high level to a logic low level at transition **213**. The value of the peak counts **202** falls to a count of 20 at floating count window **214**, pushing the floating count window **214** in a downward direction; however, the output signal **128** remains at a logic low level because the change is in the same direction as the previous change. At floating count window **216**, the peak counts **202** increase to 22; however, the floating count window is larger than two, so the increase from the count of 20 to the count of 22 is insufficient to shift the floating count window **216** up, and thus the output signal **128** remains at a logic low level.

At floating count window **218**, the value of the peak counts **202** has increased to 27, which is sufficient to shift the floating count window **218** up. In response to or in conjunction with the floating count window shifting, the output signal **128** of the comparator **126** transitions from the logic low level to the logic high level at transition **219**.

The peak counts **202** may vary over time as shown. At peaks **220** and **222**, the count value is 31, while at peak **224**, the count value is only 26. However, by utilizing a shifting of the floating count window, the variations in the peak count **202** can still be used to discriminate between a damped signal versus an undamped signal based on the transitions **205**, **213**, and **219** reflecting when the state of the system changes. Such transitions may reflect when the metallized portion of the wheel **102** is proximate to the inductor **106** of the resonant tank, for example.

While the example of the system **100** in FIG. **1** depicted an LC tank **103** that was passively energized or that may have been initially energized by a power source (not shown), it should be understood that the metering circuit **104** may energize the LC tank **103** or another resonant circuit to initiate the ringing waveform. An example of a metering circuit **104** that can energize the resonant tank is described below with respect to FIG. **3**.

FIG. **3** is a block diagram of a system **300** including a metering circuit **104** employing a floating count window to determine a count according to a second embodiment. In the illustrated example, metering system **300** includes metering circuit **104** coupled to a resonant circuit **103**. In another embodiment, resonant circuit **103** may be replaced with a capacitive sense circuit, a Wheatstone bridge (magneto resistive) circuit, or other circuitry adapted to produce a measurable signal in response to a parameter to be measured. In an embodiment, resonant circuit **103** may be an inductor-capacitor (LC) tank circuit configured to produce a resonant signal that varies based on a rotational position of the wheel **102**. In an example, the resonant signal may have a first signal characteristic when a non-metallized portion of the wheel **102** is proximate to the resonant circuit **103** and may have a second (damped) signal characteristic when a metallized portion of the wheel **102** is proximate to the resonant circuit **103**.

The metering circuit **104** may include a pulse generator **310** and a sensor circuit **302**, which are coupled to a controller, which may be implemented as a FSM **130**. The FSM **130** may also be coupled to the MCU **136** and to count registers **132** and **134**. In an embodiment, the FSM **130** may be implemented as processor readable instructions executing on a processor or on the MCU **136**. In accordance with another embodiment, the FSM **130** may be implemented as a dedicated hardware implementation including, but not limited to, application specific integrated circuits, programmable logic arrays, and other circuit devices.

The sensor circuit **302** includes the comparator **116** having a first input coupled to the resonant circuit **103** to receive an input signal. The first input may also be coupled to a bias source **304** adapted to level shift the input signal. In an embodiment, the bias source **304** may level shift the input signal to a level that is approximately half of rail-to-rail voltage. The comparator **116** further includes a second input coupled to DAC **118** to receive a reference signal, and includes an output coupled to a counter **120**. The counter **120** includes an output coupled the count discriminator circuit **122**. In particular, the output is coupled to a first input of a comparator **126**, which has a second input coupled to a floating count window **124** and an output coupled to the FSM **130**. The floating count window **124** may include a high peak threshold **306** and a low peak threshold **308**, which define the boundaries of the floating count window or count threshold window. The comparator **126** is adapted to receive a count from the counter **120** and to compare the count to the floating count window **124**, and to produce an output signal **128** corresponding to a result of the comparison.

The FSM **130** includes a count detection circuit **312** coupled to the first input of the comparator **116**. In an embodiment, the count detection circuit **312** may determine when a count at the output of counter **120** is within the floating count window **124**. When the count is within the floating count window **124**, the output signal **128** remains unchanged. However, when the count varies from the floating count window, the FSM **130** causes the floating count window **124** to change, shifting the floating count window to match the count. Additionally, when the count causes the floating count window **124** to change direction relative to a previous shift, comparator **126** toggles the output signal **128**. The size of the floating count window may remain constant and may be configured to be less than an average difference between a high peak count corresponding to an undamped state of the system and a low peak count corresponding to a damped state of the system.

In an embodiment, the FSM **130** may cause the pulse generator **310** to provide an excitation signal to the resonant circuit **103**. The sensor circuit **302** may receive an input signal in response to the excitation signal. The comparator **116** may compare the input signal to a reference signal from the DAC **118** and may produce an output signal that has a logic high level when the input signal exceeds the reference signal and a logic low level when the input signal falls below the reference signal. The output of the comparator **116** is provided to the counter **120**, which counts the pulses and provides a count of the pulses to the comparator **126**. The comparator **126** compares the count to a floating count window **124** and produces an output signal **128** representing the state of the system **100**. In an embodiment, the output signal **128** of the comparator **126** toggles when the count causes the floating count window to shift in a different direction from a previous shift. As long as changes to the count do not push the window or continue to push the window in the same direction, the output signal **128** remains unchanged.

The count detection circuit **312** of the FSM **130** may monitor the count at the output of the counter **120**, and the FSM **130** may adjust the high count threshold **306** and the low count threshold **308** by the same amount. In an embodiment, the FSM **130** may increment both the high count threshold **306** and the low count threshold **308** when the count exceeds the floating count window, and may decrement both the high count threshold **306** and the low count threshold **308** when the count falls below the floating count threshold.

In an embodiment, the FSM **130** may be configured to adjust the size of the floating count window **124** (by adjusting one or the other of the high count threshold **306** and the low count threshold **308**), for example, when the floating count window **124** does not change for a period of time that exceeds a time threshold. When the floating count window **124** is moved by the count from counter **120**, the FSM **130** may continue to monitor the counts to determine an average high count and average low count and may configure the size of the floating count window **124** to be less than the difference between the average high count and average low count. In an example, the FSM **130** may configure the floating count window **124** to have a size that is less than half of the difference between the average high count and the average low count.

While the illustrated example of FIG. **3** depicts a single resonant circuit **103**, other types of circuits may be used, including a capacitive sense circuit, a magnetic circuit, a Wheatstone bridge circuit (magneto resistive), or other circuitry adapted to produce a measurable signal in response to a parameter to be measured. Additionally, in some embodiments, a second resonant circuit may be coupled to a second sensing circuit within the metering circuit **104**. In an embodiment of the metering circuit **104** that is configured to monitor rotation of a wheel, **102** sensing circuits (such as first and second resonant circuits) may be positioned adjacent to the wheel **102** and spaced apart from one another to provide dual measurement signals, which can be processed to determine the rate of rotation as well as the direction. In this example, as a metallized portion of the wheel is proximate to one of the resonant circuits, the input signal to the sensing circuit may be dampened. In contrast, when a non-metallized portion of the wheel **102** is proximate to one of the resonant circuits, the input signal to the sensing circuit may be undamped. One possible example of a metering system including a metering circuit that can receive two different resonant signals is described below with respect to FIG. **4**.

FIG. **4** is a block diagram of a metering system **400** including a metering circuit **402** employing a floating count window **124** to determine a count according to a third embodiment. The metering circuit **402** is configured to receive a signal from two external circuits, which in this embodiment included resonant tank circuits. In the illustrated example, the metering circuit **402** includes all of the elements of metering circuit **104** of FIGS. **1** and **3**, including sensor circuit **302**, FSM **130**, pulse generator **310**, MCU **136**, and count registers **132** and **134**. Further, the metering circuit **402** includes additional circuitry to facilitate operation with two input signal sources, such as resonant tank circuits.

The metering circuit **402** includes the pulse generator **310** coupled between the FSM **130** and an output **414**, which may be implemented as a pad, pin or contact location configurable to interconnect with an external circuit. The metering circuit **402** further includes an input **418**, which may be implemented as a pad, pin, or contact location configurable to interconnect with an external circuit. The input **418** may be coupled to the sensor circuit **302**.

The sensor circuit **302** includes the comparator **116** having a first input coupled to input **418** and to the bias source **304**, a second input coupled to the DAC **118**, and an output coupled to the counter **120**. The counter **120** includes an output coupled to a first input of the comparator **126**, which includes a second input coupled to the floating count window **124** and includes an output.

The metering circuit **402** further includes a pulse generator **454** coupled between the FSM **130** and an output **452**, which may be implemented as a pad, pin or contact location configurable to interconnect with an external circuit. The metering circuit **402** further includes an input **458**, which may be implemented as a pad, pin, or contact location configurable to interconnect with an external circuit. The input **458** is coupled to a sensor circuit **460**.

The sensor circuit **460** includes a comparator **464** having a first input coupled to the input **458** and to a bias source **473**, a second input coupled to a DAC **466**, and an output coupled to a counter **468**. In an example, the bias source **473** may include a voltage configured to level shift the input signal. Further, DAC **466** may be the same as the DAC **118**, depending on the implementation. The counter **468** includes an output coupled to a first input of a comparator **470**, which includes a second input coupled to a floating count window **472**. The comparator **470** further includes an output.

The metering circuit **402** includes a controller, which may be implemented as the FSM **130**. The FSM **130** includes outputs coupled to pulse generators **310** and **454**. Further, the FSM **130** includes an input coupled to the output of comparator **126** and an input coupled to the output of comparator **470**. The FSM **130** also includes an output coupled to count register **132** and an output coupled to count register **134**. Additionally, the FSM **130** includes outputs coupled to floating count windows **124** and **472**. The metering circuit **402** further includes a microcontroller unit (MCU) **136** coupled to count registers **132** and **134**. MCU **136** may include a plurality of connections (not shown) to communicate with other circuitry of metering circuit **402** (such as transceivers, memory, and other circuits).

The external resonant tank circuits may be configured to generate a resonant signal that has damping characteristics that vary based on a parameter to be sensed. In the illustrated example, the resonant circuits are LC tank circuits including a first resonant tank circuit that includes a transistor **404** coupled between a power supply and a node **405**, and including a gate coupled to output **414** of metering circuit **402**. The first resonant tank circuit further includes an inductor **406** and a capacitor **408** coupled in parallel between node **405** and a second power supply, such as ground. Additionally, the first resonant tank circuit is AC coupled to input **418** through capacitor **410**, which is coupled between node **405** and input **418**.

The resonant tank circuits further include a second resonant tank circuit having a transistor **444** coupled between a power supply and a node **445**, and including a gate coupled to output **452** of metering circuit **402**. The second resonant tank circuit further includes an inductor **446** and a capacitor **448** coupled in parallel between node **445** and a second power supply, such as ground. Additionally, the second resonant tank circuit is AC coupled to input **458** through capacitor **450**, which is coupled between node **445** and input **458**.

In an embodiment, the FSM **130** sends a signal to pulse generator **310**, causing pulse generator **310** to apply an excitation signal or pulse to output **414**. The excitation signal biases transistor **404** to briefly couple the power supply to node **405**, charging capacitor **408**. When the excitation signal is stopped (i.e., the pulse ends), transistor **404** decouples the power supply from node **405**. Charge stored by capacitor **408** is discharged into inductor **406**, building up a magnetic field around the inductor **406** and reducing the voltage stored by the capacitor **408**. When the capacitor **408** is discharged, the inductor **406** will have the charge stored in its magnetic field and since the inductor **406** resists changes in current flow, the energy to keep the current flowing is extracted from the magnetic field, which begins to decline, and the current flow will charge the capacitor **408** with a voltage of opposite polarity to its original charge. When the magnetic field of inductor **406** is dissipated, the current stops and the opposite polarity charge is stored in capacitor **408**. The discharge/recharge process is repeated with the current flowing in the opposite direction through the inductor **406**. The energy oscillates back and forth between the capacitor **408** and the inductor **406** until (if not replenished by power from an external circuit, such as the power supply through transistor **404**) internal resistance makes the oscillations die out. When used in conjunction with a metering wheel **102** that has a metallized portion, the oscillations die out faster (damped) when the metallized portion is proximate to the resonant tank circuit and die out slower (undamped) when the non-metallized portion is proximate to the resonant tank circuit.

The comparators **126** and **470** compare the counts from counters **124** and **468**, respectively, to discriminator thresholds from floating count windows **124** and **472**, respectively. The comparator **126** produces an output indicating a state (damped or undamped) of the system **400** as determined from the input signal received at input **418**. Similarly, the comparator **470** produces an output signal indicating a state (damped or undamped) of the system **400** as determined from the input signal received at the input **458**.

In an embodiment, the FSM **130** uses the count detection circuit **312** of the FSM **130** to monitor the pulse counts from counters **120** and **468**. The FSM **130** may selectively alter the floating count windows **124** and **472** when the output signals at the outputs of comparators **126** and **470** toggle. In an example, the floating count window **124** may have a different value from the floating count window **472**, and the FSM **130** may update the floating count windows **124** and **472** independently.

FIG. **5** is a flow diagram of a method **500** of determining a count using a floating count window according to an embodiment. At **502**, a resonant signal is received at an input of a metering circuit. In an embodiment, the resonant signal may be received from an LC tank circuit. In another embodiment, the resonant signal may be received from another signal source that produces a ringing waveform.

Advancing to **504**, the resonant signal is compared to a peak threshold using a comparator of the metering circuit. Continuing to **506**, a number of peaks of the resonant signal that exceed the peak threshold are counted. In an embodiment, the peaks are counted using a counter of the metering circuit. Advancing to **508**, the count is compared to a count threshold window. In an embodiment, the count threshold window may be defined by a low threshold and a high threshold.

Continuing to **510**, if the count is greater than the count threshold window, the method **500** advances to **512** and the count threshold window is shifted up such that the top (upper count threshold) of the count threshold window matches the count. The method **500** then proceeds to **514**. At **514**, if shifting the threshold window up constitutes a change in direction of the movement of the floating count window, the method **500** advances to **516** and the comparator **126** changes the output signal **128** at its output in the direction of the window shift (i.e., it transitions from a logic low level to a logic high level). Otherwise, at **514**, if the floating count window has not changed direction, the method **500** continues to **518** and no change is made to the output signal at the output of the comparator. The method then returns to **502** to receive a next resonant signal.

Returning to **510**, if the count is not greater than the count threshold window, the method **500** proceeds to **520**. At **520**, if the count is less than the count threshold window, the method **500** proceeds to **522** and the count threshold window is shifted down such that the bottom of the count threshold window matches the count. The method **500** then proceeds to **514**. At **514**, if shifting the threshold window down constitutes a change in direction of the movement of the floating count window, the method **500** advances to **516** and the comparator **126** changes the output signal **128** at its output in the direction of the window shift (i.e., it transitions from a logic high level to a logic low level). Otherwise, at **514**, if the floating count window has not changed direction, the method **500** continues to **518** and no change is made to the output signal at the output of the comparator. The method then returns to **502** to receive a next resonant signal.

Returning to **520**, if the count is not less than the count threshold window, the method **500** advances to **518**, and no change is made to the output signal at the output of the comparator. The method then returns to **502** to receive a next resonant signal.

FIG. **6** is a flow diagram of a method **600** of determining a count using a floating count window according to a second embodiment. At **602**, a count is received that corresponds to the peaks of a resonant signal. The count may be received at a first input of a comparator. Advancing to **604**, the count may be compared to a floating count window. The comparator may compare the count to a high threshold and/or a low threshold to determine whether the count falls within the floating count window.

Continuing to **606**, an output signal is selectively altered in response to comparing the count to the floating count window. In an embodiment, the output signal toggles from a first state to a second state when the count falls outside of the floating count window. In an embodiment, the output signal toggles in the direction of the count relative to the floating count window, such that if the count is below the floating count window, the output signal toggles from a logic high level to a logic low level or remains at a logic low level if the output signal is already at a logic low level.

Proceeding to **608**, the count window is selectively shifted in the direction of the count when the count is outside of the count window. In an example, the count window is shifted down when the count falls below the count window and is shifted up when the count is above the count window.

In an embodiment, the floating count window is shifted up to match the count when the count exceeds an upper threshold of the floating count window. In another embodiment, the floating count window is shifted down to match the count when the count falls below a lower threshold of the floating count window. In still another embodiment, the floating count window is unchanged when the count falls within the floating count window.

In an embodiment, the output signal toggles to represent a state of a system when the count falls outside of the floating count window in a direction that differs from a previous shift of the floating count window. In still another embodiment, the output signal is toggled from a logical low level to a logical high level when a previous shift of the floating count window reflected a downward shift and the count exceeds an upper threshold of the floating count window. Further, the output signal is left unchanged when the previous shift of the floating count window reflected an upward shift. In yet another embodiment, the output signal toggles from a logical high level to a logical low level when a previous shift of the floating count window reflected an upward shift and the count falls below a lower threshold of the floating count window. The output signal remains unchanged when the previous shift of the floating count window reflected a downward shift.

In conjunction with the circuits and methods described above with respect to FIGS. **1-6**, the metering circuit uses a floating count window to determine when the system changes from a first state to a second state. By utilizing a floating count window, the metering circuit may accurately detect the rotational state of the wheel without calibration. Thus, the metering circuit can correctly detect changes in the metering wheel even in the face of changes in temperature and voltage that might alter a threshold voltage. Instead of having to do numerous calibrations to correct the threshold, the floating window tracks the wheel movement.

In accordance with various embodiments, the floating count window and the methods described herein may be implemented in hardware or as processor readable instructions executing on a processor or on the MCU **136**. In accordance with another embodiment, the floating count window and the methods described herein may be implemented using a dedicated hardware implementation including, but not limited to, application specific integrated circuits, programmable logic arrays, and other hardware devices can likewise be constructed to implement the methods described herein.

The illustrations, examples, and embodiments described herein are intended to provide a general understanding of the structure of various embodiments. The illustrations are not intended to serve as a complete description of all of the elements and features of apparatus and systems that utilize the structures or methods described herein. Many other embodiments may be apparent to those of skill in the art upon reviewing the disclosure. Other embodiments may be utilized and derived from the disclosure, such that structural and logical substitutions and changes may be made without departing from the scope of the disclosure. Moreover, although specific embodiments have been illustrated and described herein, it should be appreciated that any subsequent arrangement designed to achieve the same or similar purpose may be substituted for the specific embodiments shown.

This disclosure is intended to cover any and all subsequent adaptations or variations of various embodiments. Combinations of the above examples, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the description. Additionally, the illustrations are merely representational and may not be drawn to scale. Certain proportions within the illustrations may be exaggerated, while other proportions may be reduced. Accordingly, the disclosure and the figures are to be regarded as illustrative and not restrictive. Workers skilled in the art will recognize that changes may be made in form and detail without departing from the scope of the disclosure.

What is claimed is:

1. A method comprising:

receiving a count corresponding to a number of peaks of a resonant signal that exceed a reference signal;

comparing the count to a floating count window defined by a first count threshold and a second count threshold, the first count threshold is larger than the second count threshold; and selectively shifting the floating count window in a direction of the count when the count falls outside of the floating count window.

2. The method of claim **1**, further comprising shifting the floating count window up to match the count when the count exceeds the first threshold of the floating count window.

3. The method of claim **1**, further comprising shifting the floating count window down to match the count when the count falls below the second threshold of the floating count window.

4. The method of claim **1**, further comprising leaving the floating count window unchanged when the count falls within the floating count window.

5. The method of claim **1**, further comprising selectively toggling an output signal to represent a state of a system when the count falls outside of the floating count window in a direction that differs from a previous shift of the floating count window.

6. The method of claim **5**, further comprising:

toggling the output signal from a logical low level to a logical high level when a previous shift of the floating count window reflected a downward shift and the count exceeds the first threshold of the floating count window; and

leaving the output signal unchanged when the previous shift of the floating count window reflected an upward shift.

7. The method of claim **5**, further comprising:

toggling the output signal from a logical high level to a logical low level when a previous shift of the floating count window reflected an upward shift and the count falls below the second count threshold; and

leaving the output signal unchanged when the previous shift of the floating count window reflected a downward shift.

8. The method of claim **5**, further comprising reducing a size of the floating count window when the floating count window does not shift for a period of time that exceeds a time threshold.

9. A metering circuit comprises:

a first comparator including an input to receive a resonant signal, a second input to receive a reference signal, and an output;

a counter including an input coupled to the output and including an output to provide a count corresponding to a number of peaks of the resonant signal that exceed the reference signal; and

a second comparator to compare the count to a floating count window defined by a first count threshold and a second count threshold; and

a controller coupled to an output of the comparator and configured to selectively shift the floating count window in a direction of the count.

10. The metering circuit of claim **9**, wherein the second comparator selectively toggles an output signal in response to the comparison when the controller shifts the floating count window in a direction that differs from a direction of a previous shift of the floating count window.

11. The metering circuit of claim **8**, wherein the controller shifts the floating count window when the count is outside of the floating count window.

12. The metering circuit of claim **11**, wherein the controller shifts the floating count window up to a level corresponding to the count when the count exceeds the first threshold of the floating count window.

13. The metering circuit of claim **11**, wherein the controller shifts the floating count window down to a level corresponding to the count when the count falls below the second threshold of the floating count window.

14. The metering circuit of claim **9**, wherein the controller decreases a size of the floating count window when the floating count window does not shift for a period of time that exceeds a time threshold.

15. The metering circuit of claim **9**, wherein the floating count window has a size corresponding to a pre-determined number of counts.

16. An apparatus comprising:

a first comparator having a first input to receive an input signal, a second input to receive a reference signal, and an output;

a counter having an input coupled to the output of the first comparator, and including an output to provide a count; and

a count discriminator circuit to compare the count from the counter to a floating count window and to shift the floating count window to match the count when the count falls outside of the floating count window.

17. The apparatus of claim **16**, wherein the count discriminator circuit selectively toggles an output signal at the output when the shift of the floating count window differs from a previous shift.

18. The apparatus of claim **17**, further comprising a controller coupled to the output of the count discriminator circuit and adapted to selectively update one of a first counter and a second counter in response to the output signal.

19. The apparatus of claim **17**, further comprising a controller to receive the output signal and to selectively adjust a size of the floating count window when the output signal does not toggle for a period of time that exceeds a time threshold.

20. The apparatus of claim **16**, wherein the floating count window has a size that is smaller than a difference between a first peak count and a second peak count of the number of peaks of the input signal, the first peak count having a larger number of counts than the second peak count.

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